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AN ANALYSIS OF FRACTURES AROUND THE SEVIER FAULT ZONE IN RED HOLLOW CANYON NEAR ORDERVILLE, UTAH

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ABSTRACT

Structural discontinuities - such as opening mode joints, shear fractures, and faults - tend to occur in close geographic proximity to one another; however, timing relationships between these structures are not always easy to discern in the field. In southwestern Utah, the Jurassic Navajo Sandstone is cut by large-scale normal faults associated with the Sevier Fault Zone, making it perfect for observing several fracture types. The aim of this study is to complete a dynamic and kinematic analysis of the fractures near a major fault and to determine the chronologic relationships between the fractures. Specifically, we observed an unnamed segment of the Sevier Fault Zone - herein referred to as the Mountain Lion Den Fault (MLD) - previously interpreted as a west dipping normal fault striking 030. The primary field area is the Red Hollow Canyon/Elkheart Cliffs region, located southeast of Orderville, Utah.

For this study, orientations (dip and dip direction) of fracture data within the Navajo Sandstone were measured and tracked on eight different scanlines. Scanline fractures were plotted on stereonets and averages determined. GPS locations were taken on a Trimble G7X at ends of each scanline for GIS mapping.

Fracture analyses show a general NNE strike similar to the MLD Fault strike. Despite a few outliers, scanline averages typically strike within 10°-15° of the 030 strike of the MLD Fault. We interpret movement along the fault initiated around the same time some of the fractures formed. The fractures likely formed in front of the MLD Fault at oblique angles to its strike as the fault propagated northward. These results suggest that an area of weakness formed in Red Hollow Canyon, allowing the fault to propagate easily at 030. These results compare favorably to previous brittle fracture studies within propagating fault zones. Outliers in the data could be associated with NW rotation of σ_3, similar to nearby joints in Zion National Park.

INTRODUCTION

In the western US, there are multiple physiographic provinces. In southern Utah, the Colorado Plateau and the Basin and Range provinces dominate, with the Transition Zone between them. Marked by changes in deformation, volcanism, topography, and crustal structure, the Colorado Plateau gradually gives way to the Basin and Range province in the west (Jackson, 1990b, 1990a; Porter et al., 2017). The Basin and Range is the result of large scale extension that created characteristic elongate valleys, north to north-northeast trending mountain ranges, and gently dipping strata. Extension produced large normal faults, horsts and grabens, as well as a variety of other structures including relay ramps (Stewart, 1998). The Transition Zone contains characteristics from both provinces and extension is interpreted to be ongoing (Eaton, 1982; Stewart, 1998).

In southern Utah there are four main faults/fault zones that accommodate extension across the Transition Zone, including the Grand Wash Fault Zone, the Hurricane Fault, the Sevier Fault Zone, and Paunsaugunt Fault. This study focuses on a portion of the Sevier Fault Zone (SFZ), near Orderville, Utah. This fault zone has many fault segments that accommodate regional extension. These segments are high angle, west-dipping normal faults generally striking 030. Initial displacement along the SFZ started around 15 to 12 Ma, and the fault zone has produced two historical earthquakes, implying that it is still active (Eaton, 1982; Moores and Twiss, 1995; Davis, 1999).

Data collection for this study occurred in the Elkheart Cliffs and Red Hollow Canyon regions. In the Elkheart Cliffs area, only one fault accommodates extension, whereas Red Hollow Canyon (RHC) is in a transfer zone and contains multiple fault segments. Specifically, fracture data were gathered along the Elkheart Cliffs Fault (EHC), Mountain Lion Den Fault (MLD), and a potential small fault segment crossing the canyon between the MLD and EHC Faults (Doelling, 2008), which strikes at 025 and will be referred to as the Kimbler Fault (Figure 1). West of RHC is a fault that forms the Orderville Relay Ramp with the Elkheart Cliffs Fault and briefly follows Highway 89; this fault is referred to as the Highway 89 Fault (H89).

As subsidiary structures to faults, fractures are useful in interpreting the history of an area. Fractures are planar discontinuities that form to help accommodate stress. In the field, indicators of fractures included extremely flat faces along exposures, cracks in outcrops, and hackle plume structures. There are three main modes of fracturing: Mode 1 are opening fractures also called joints, Mode 2 are sliding fractures, and Mode 3 are tearing fractures. For dip-slip faults, Mode 2 tends to be on the top and bottom tips of fault planes, and fractures on the lateral tips tend to be Mode 3. These modes can form at the same time as Mode 1 fractures, creating zones of mixed mode fracturing (McGrath and Davison, 1995).

METHODS

Scanlines

While collecting fracture data in the canyons, scanlines were established. For purposes of this study, scanlines are used to measure fracture position relative to an arbitrary starting position (usually where good outcrop exposure made fracture documentation possible), approximately perpendicular to the orientation of a dominant fracture set. Positions (in meters) were recorded between each visible fracture greater than 4-m in height. There are large gaps in some of the scanlines, indicating the absence of visible fractures or the lack of accessible outcrops. GPS locations were taken on a Trimble G7X to mark the beginning and end of each scanline.

Fracture Data

More than 200-m thick in the study area, the well-exposed Navajo Sandstone is excellent for data collection. When determining if a fracture's attitude was to be recorded, its length and accessibility were considered. If the visible portion of the fracture extended 4 or more meters (12 feet), its attitude (dip, dip direction) was recorded using a Brunton geologic compass. Fractures that were similar in attitude to the first fracture on the scanline were labeled 'typical' fractures, and those varying noticeably from that orientation were labeled 'diamond' fractures. It is important to note that fracture orientation data were collected by multiple geologists in the field, so there may be some human error included in the data collected. Sketches and photo documentation of fractures were done in the field as well.

Stereonets

Stereonet software (Allmendinger, 2018) was used to visualize fracture orientations. Fracture data were organized into .csv files, brought into Stereonet, and plotted. The stereographic projections were analyzed to find spatial patterns. Strike and dip averages were calculated using excel, not taking dip direction into account when determining the dip averages due to the uncertainty of the validity of the recorded dip direction.

RESULTS

Several trends are apparent in the scanline fracture data shown in Table 1. Numerically averaged dips for all fractures (except H◊) are within 14° of each other. Strike averages for scanlines A, B◊, C, C◊, D, E, and G only differ by a maximum of 18°, ranging from 019 to 037. The MLD Fault strikes at 030, the Kimbler Fault at 025, and the EHC Fault at 020 (Schiefelbein, 2002; Doelling, 2008); these faults correlate well to the above listed fracture averages. Though most fracture data trend NNE, scanline divisions E◊ and H◊ have strike averages that trend NNW.

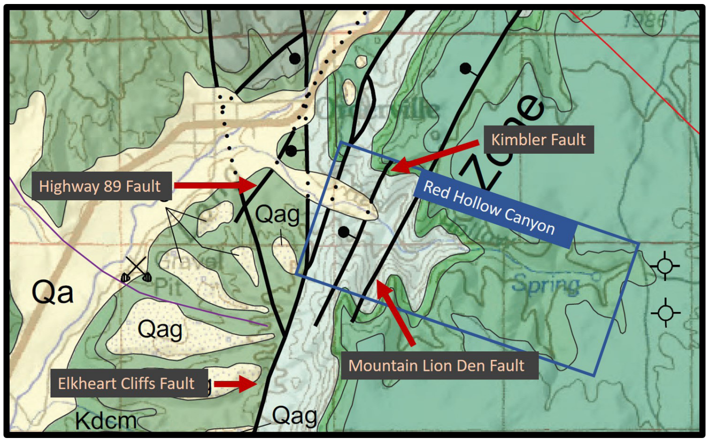

Figure 1. Geologic map of the portion of the SFZ in which the study was conducted. RHC emphasized with blue box (Modified from Doelling, 2008).

DISCUSSION

Fault-related Fractures

Fractures that form at tips of normal faults tend to be parallel or subparallel to the fault strike and form first, creating a weak zone for the fault to propagate through (McGrath and Davison, 1995; Kattenhorn et al., 2000). Fracture strike averages from near the MLD Fault are similar to the fault strike, seen in Figure 3, and the same holds true for the Elkheart Cliffs region. This suggests that the faults and fractures are genetically related. The similarity between these faults and fractures implies a close chronological relationship; the fractures around the MLD, Kimbler, and EHC Faults formed shortly before the faults, creating paths of least resistance in which the faults could form.

Isolated Fractures

Rogers et al. (2004) analyzed fractures in Zion National Park and found three main sets that trend NNE, NNW, and NW in chronological order from oldest to youngest. Since Rogers et al., (2004) were able to find timing relations between their observed fracture sets, they concluded that the regional stress regime rotated from NNE to NW over time. Zion is geographically close to both localities in this study, so there may be connections between the structures seen at both locations. Our data correlate to the older strike orientations of Rogers et al.'s (2004) sets; however, mostly NNE trending fractures were seen in RHC rather than the dominantly NNW fractures seen in Rogers et al.'s (2004) paper.

Regional Stress Regime

For idealized Andersonian normal faults, σ_1 is perpendicular to the surface of Earth, and σ_3 is in the direction of extension. This means σ_3 is perpendicular to the fault strike (Peacock, 2002). Kattenhorn et al. (2000) found that fractures of similar age to a nearby normal fault will be parallel to sub-parallel to the fault strike. So, if a fault strikes at 025 (the average of the MLD, Kimbler, and EHC Faults), then the trend of σ_3 would be 115/295. Thus, a regional σ_3 trending ESE/WNW was present when the faults and related fractures formed. Rogers et al. (2004) also found a WNW trending σ_3 for a fracture set that over time changed to WSW and then to a SW trending σ_3, indicating a rotation of the regional stress regime. Since we also see a difference in fracture strikes from NNE to NNW, our data support the σ_3 regional rotation hypothesis from Rogers et al. (2004).

Fault Propagation

The structural data presented here indicates that the factures in RHC are close in age to the MLD Fault and associated nearby faults within the SFZ. For the MLD fault, the exact plane where the actual displacement occurred is difficult to define within the canyon due to erosion, landslides, and vegetation (Figure 4). However, displacement of the above Temple Cap

Table 1. Average strikes and numerical dip averages for typical and diamond fractures.

Scan-line	Number of Frac-tures	Typical Fractures Average		Diamond Frac-tures Average	
		Strike	Dip	Strike	Dip
A	102	020	88	-	-
B	81	054	88	027	81
C	47	030	84	025	75
D	31	021	74	-	-
E	18	019	82	348	84
F	39	010	82	-	-
G	24	032	79	-	-
H	33	037	85	352.5	63.5

Formation is clearly visible on the hanging wall on the north side of the canyon (Figure 4). Looking south along the approximate fault strike, no offset can be seen across the canyon. The offset and the oblique orientation of the fractures to the main fault plane indicate that the fault likely traveled north. Due to the absence of displacement of the Temple Cap on the south side of the canyon, our results suggest that the MLD segment began in RHC and propagated northward.

Northward propagation of the MLD Fault is likely

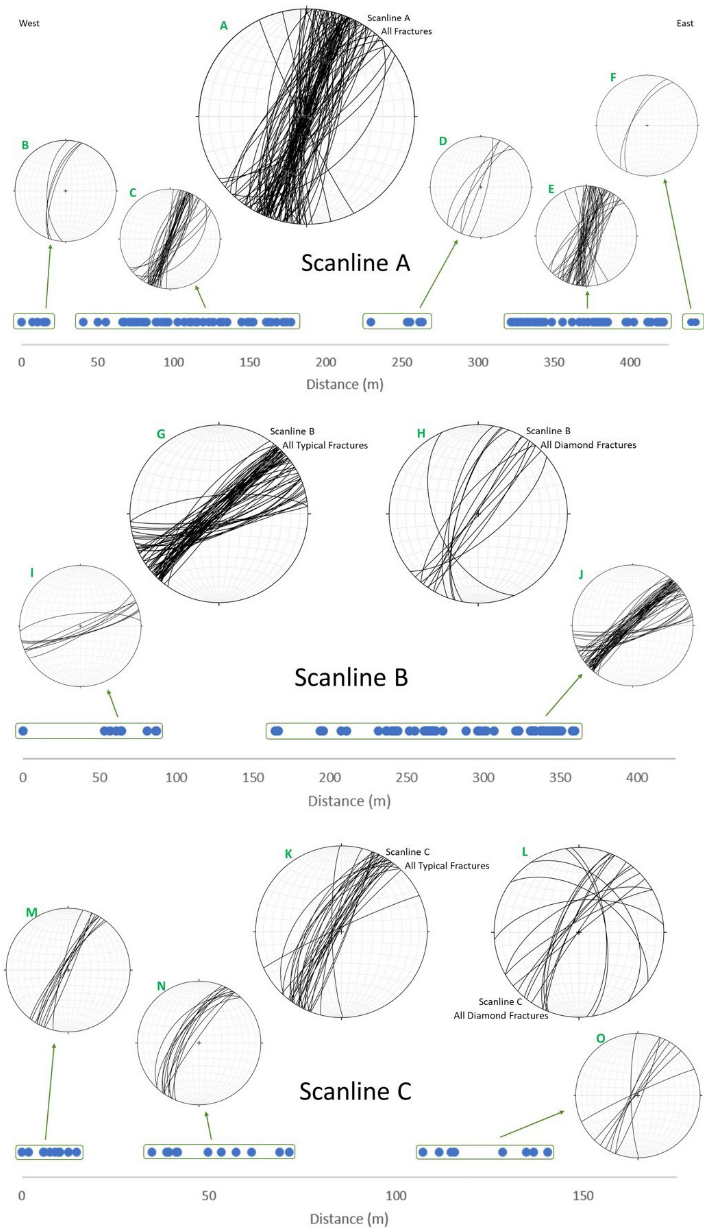

Figure 2. A-O. Stereonets of scanlines A, B, and C, plotted spatially along their respective scanline with groupings indicated by boxes.

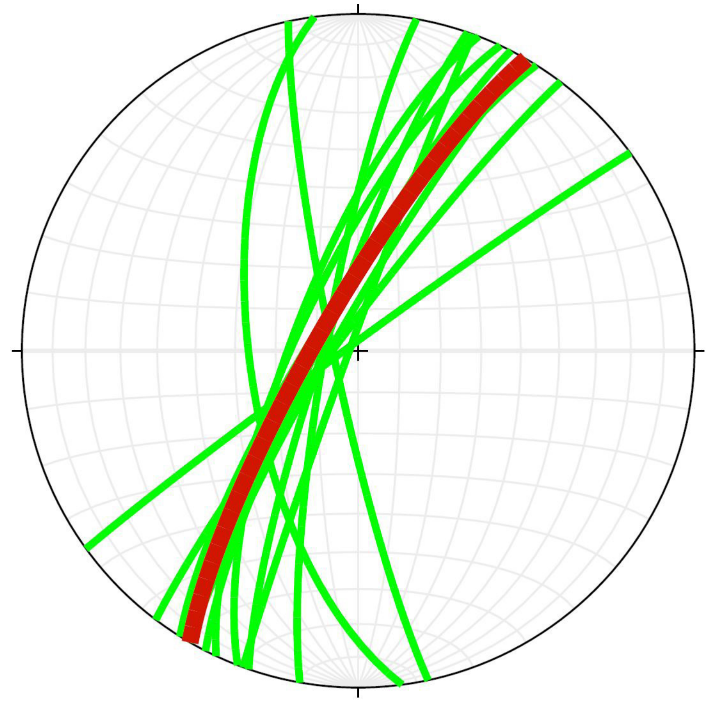

Figure 3. Stereonet showing typical and diamond fracture group averages from all scanlines (green) and the Mountain Lion Den Fault strike (red).

because the EHC Fault ends just northwest of the canyon, where a relay ramp connects it to the H89 Fault. The displacement of the EHC Fault stopped and additional offset accommodation was necessary, likely initiating the formation of the MLD Fault. However, because the H89 Fault also starts around where the EHC Fault stops, more research is needed to determine why the displacement was split between the MLD and H89 segments.

CONCLUSION

From these data, we conclude that:

• most fractures in Red Hollow Canyon and Elkheart Cliffs are related to the Mountain Lion Den, Kimbler, and Elkheart Cliffs Faults.

• the fault-related fractures are close in age to the fault(s) with which they are associated.

• data from this study supports the stress regime rotation theory of Rogers et al. (2004).

• the Mountain Lion Den Fault began in Red Hollow Canyon and propagated northward.

Figure 4. Photograph along the approximate MLD Fault strike. Temple Cap Formation sunlit in the background. Left side of the photo is the hanging wall and the right is the footwall. Estimated fault strike is circled. View to the NNE (Photo credit: Ben Surpless).

Studies of additional complex normal faulting regions in southern Utah would help support this study. To continue this research, more data could be collected along the Mountain Lion Den Fault, following it northward. Also, collecting more fracture data along the Elkheart Cliffs Fault, Kimbler Fault, and a heavily fractured zone east of this study's focus would provide valuable insight into how stress was accommodated in this complexly faulted region.

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